

the degree of accuracy with which the data show its *changes* of temperature. The data have been subjected to various forms of analysis which need not be described here. As a result, it is felt that they are entirely adequate to show the changes that are taking place in any region in which the areal distribution of temperature is fairly uniform and the disposition of the observations reasonably constant. A region like that between New York and Bermuda must, however, be excepted, on account of the great mixture of warm and cold waters found there. Probably no single group of observations, such for instance as those taken by all vessels crossing

the region in a given month, could be depended upon to give the true mean surface temperature of such a region as a whole, even though the individual observations were highly accurate. Even continuous records of temperatures, obtained by means of sea water thermographs, might not suffice for more than the ships' courses in these regions of exceptional temperature range. The Weather Bureau has recently installed such an instrument on a vessel plying between New York and Porto Rico and it hopes that the data which will soon be available will shed further light on this important subject.

RECENT INVESTIGATIONS ON THE ENERGY IN THE EARTH'S ATMOSPHERE, ITS TRANSFORMATION AND DISSIPATION

551.511

By EDGAR W. WOOLARD

In the physical system of the earth's atmosphere, we find numerous forms of energy displayed on a gigantic scale; and transformations from one form to another are continually taking place (1). Kinetic energy, in particular, is constantly being dissipated—transformed by friction and turbulence into heat which is ultimately radiated away—and hence a continuous supply of energy must be available to maintain the ceaseless activity of the atmosphere against the action of the resisting influences. The only available adequate source of all except an infinitesimal amount of atmospheric energy is ultimately the solar radiation which is intercepted by the earth (2). The atmosphere acts like a gigantic heat-engine, transforming radiant energy from the sun into the energy of atmospheric phenomena; and the general problem of meteorology consists of elucidating the details of the mechanism and the processes by which, under the usual laws of dynamics and thermodynamics, this energy results in the production and maintenance of the sequence of atmospheric phenomena, these phenomena collectively making up the continual activity in the atmosphere, and involving the changes in the daily distribution of the meteorological elements that provide the daily weather for every part of the globe (3).

From the approximately known mass (4) of, and mean wind velocities in, the earth's atmosphere, Brunt (5) concludes that the total *kinetic* energy of the *general* or *planetary* circulation is of the order of 3×10^{27} ergs; considerable additional kinetic energy is frequently developed in storms, as Shaw has pointed out (6). The equations of motion show that the rate of dissipation of kinetic energy due to the virtual internal friction introduced by turbulence is equal to the product of the pressure gradient into the component of wind velocity in the direction of that gradient. In steady motion along an isobar (frictionless gradient wind) there is no dissipation, but if, due to turbulence, there exists any motion across an isobar into lower pressure, there is a dissipation; and a steady motion can be maintained only if energy is supplied at a rate equal to the product of velocity of inflow and gradient (5).

The theory of the variation of wind velocity with height, produced by turbulence, makes possible an integration which shows that the total loss of energy due to turbulence in a column extending from the surface to the limit of the atmosphere is practically equal to the loss in the column extending from the surface to that height (about one kilometer) at which gradient direction is first attained, consequently the dissipation of energy by turbulence is, as we might expect, effectively restricted to the layer below this height (5). At greater heights, the changes of wind with elevation are deter-

mined, not by turbulence produced at the ground, but by the horizontal distribution of temperature; and the rate of loss of energy must be determined in a different way (7).

Neglecting the dissipation above 10 kilometers, Brunt finds, finally, for the rate of loss of kinetic energy above one square meter of the earth's surface (5): From surface to 1 kilometer, 3×10^{-3} kw./m.²; from 1 to 10 kilometers, 2×10^{-3} kw./m.²

If the rate of dissipation be assumed proportional to the energy remaining, the kinetic energy of the general circulation would be reduced to 0.1 its value in three days. This loss must be made up by the conversion of solar energy into kinetic energy of winds. After allowance is made for the earth's albedo of 37 per cent, the remaining 67 per cent which constitutes the effective incoming solar radiation (i. e., that which is absorbed, and in some way used up in the production of weather phenomena, before being again returned to space) is found to average for the whole earth 0.22 kw./m.²; the conversion of a little over 2 per cent of this into the particular form of kinetic energy of winds in the planetary circulation would make up for the continual dissipation of the latter¹ (5).

No completely satisfactory and universally acceptable theory has yet been put forward, however, which explains the details of the mechanism of the continuous dynamic and thermodynamic process by which solar energy is converted into atmospheric energy. The major actuating cause of atmospheric activity is undoubtedly the unequal heating and cooling in different latitudes. This sets up temperature differences that in turn set up pressure differences, and lead to a planetary circulation involving interzonal exchange of air by way of the cyclones, anticyclones, and other secondary phenomena which come into existence in the temperate zone. The highly complicated and irregular circulations thus set up are, however, far from being completely understood or accounted for.

If we regard the phenomena exhibited by separate masses of air, we have little difficulty in finding evidence of all the separate stages of the thermal cycle of a heat-engine (8). A thermodynamic engine must operate between two different temperatures. The "boiler" of the atmospheric engine is that part of the land and sea warmed above the temperature of the overlying air by

¹ The cross section of the solar beam constantly being intercepted by the earth is πR^2 . R = radius of earth; averaging the energy in this beam over the entire surface of the earth, and taking the solar constant to be 2 g. cal. per cm.² per min., we find that if the solar energy were spread uniformly over the whole earth at all times, each square centimeter would continually receive $2 \frac{\pi R^2}{4\pi R^2} = .5$ g. cal./min.; considering .37 of this to be reflected and scattered to space without ever taking any part in the thermodynamic processes of the atmosphere, we are left with .315 g. cal. per cm.² per min., or .22 kw./m.² for the effective incoming energy; 2 per cent of this is 4.4×10^{-3} kw./m.², while the total dissipation is 5×10^{-3} kw./m.².

solar radiation, together with those parts of the atmosphere which are warmed directly by solar radiation; such conditions are particularly marked in tropical regions. The "condenser" is any part of the surface of land or sea colder than the air above it, and any part of the atmosphere which is, in the net, losing heat by radiation; these conditions are most effectively present in the vast cooling surfaces of the arctic and antarctic regions. The atmosphere as a whole does no useful work—the atmospheric engine has an efficiency zero—for most of the work done is turned into heat by friction and turbulence in the air and the ocean, and ultimately radiated away. Hence in the long run there is a balance between incoming effective solar radiation and outgoing earth radiation; this necessarily follows from the fact that no part of the earth is continuously increasing or decreasing in temperature. Since in the long run the total thermal effect is immeasurably small, the solar energy which passes through the atmosphere merely maintaining the *status quo ante*, we can not deal with the relation between heat and work by regarding the whole atmosphere as a unit. The dynamical effects attributed to the heating by solar radiation combined with the cooling by earth radiation are dependent upon the differential treatment of separate parts of the atmosphere; we must therefore suppose a portion of air to be isolated, and trace the thermal changes which it undergoes.

Until comparatively recently, the manner in which the atmospheric engine works seemed to present little difficulty: The general circulation was considered to be the direct consequence of ascent of warm air at the equator and descent of cold air at the poles, there being a permanent circulation from equator to poles in the upper atmosphere, with a return flow in the surface or middle layers. Similarly, cyclones were considered to form in regions where the air was warmer than the surrounding air, with a consequent upward motion of the warm air through its colder environment; and the anticyclone was considered to be a region of cold descending air (9). However, we now know that the atmosphere is thermally stratified and hence normally restrains large-scale vertical circulations, that there is no direct and regular exchange of air between polar and equatorial regions either at the surface or aloft, that some cyclones are relatively cold and some anticyclones relatively warm; and we recognize many puzzling phenomena in connection with ordinary thermal convection. We are thus called upon profoundly to modify many of our simple conceptions and to solve many new problems (9).

Probably most of the radiant energy from the sun is first converted into some form of potential energy which is subsequently released in the form of kinetic energy, very little solar energy being converted directly into the kinetic form. The well-known mechanism of conversion suggested by Margules (10) however, is considered by Brunt to be more applicable to thunderstorms and line squalls than to the general circulation. The transfer-

ence of solar energy into kinetic energy may in part be brought about through the ascent of warm humid air within the Tropics, the ascended air moving poleward aloft, but being able to descend in middle latitudes in spite of the thermal stratification on account of cooling by radiation. It completes a cycle by moving equatorward over the surface (11); the amount of work done in the course of such a cycle has been computed by Shaw (12). Certainly the abundant rains of the doldrums (and other regions) are definite evidence that convection is operative in the atmosphere on a large scale; and the ascent of the relatively small quantity of 100 cubic kilometers of air per second to 15 kilometers, this air drifting north, cooling by radiation, descending in latitude 60°, and returning equatorward, would contribute just enough kinetic energy to the general circulation to replace the energy dissipated by turbulence. The descent of cold air over the slopes of Greenland and the Antarctic continent would also contribute some energy, but the computations of L. F. Richardson indicate that the amount so contributed can be only a very small fraction of that dissipated (5).

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CONFERENCE OF THE INTERNATIONAL COMMISSION ON SOLAR RADIATION AT DAVOS AUGUST 31 TO SEPTEMBER 2, 1925¹

551.590.2 (682.2)

By H. H. KIMBALL

There were present at the conference the following persons, who were, except the last named, members of the commission: Messrs. J. Maurer, the president; A. Ångström, Stockholm; C. Dorno, Davos; L. Gorczyński, Warsaw; H. Hergesell, Lindenberg; Chr. A. Nell, The Hague; C. Schoute, de Bilt; R. Süring, Potsdam; and F. Linke, Frankfurt.

Sessions were held on the morning and the afternoon of August 31 and on the mornings of September 1 and 2.

The following were nominated for membership on the Commission: Messrs. Åkerblom, Upsala; Linke, Frankfurt; Moll, The Hague; and Volochine, Prague.

Among the important questions considered were the following:

(1) The founding of a Central Institute for Solar Radiation.

(2) Questions of the first importance in solar radiation (standardization of pyrheliometers, transmission coeffi-

¹ Procès Verbaux de la Conférence de la Commission Internationale de Radiation Solaire à Davos 31/8-2/9, 1925.